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Runoff and Erosion Control by Seeded and Native Vegetation on a Forest Burn: Black Hills, South Dakota

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ABSTRACT

Growth of seeded species in combination with reestablishment of native vegetation reduced overland runoff and soil erosion to tolerable levels within one to four growing seasons. Gross rainfall was a poor indicator of runoff and soil erosion from small plots. Trends were best defined by declining rates of runoff and sediment production per unit of excess rainfall. Sixty percent ground-cover density (live vegetation plus litter) is postulated as the minimum necessary for soil stabilization. This cover density almost certainly could not have been reached within the 4-year study period without seeding. Seeded grasses—timothy and Kentucky bluegrass on coarse-textured soil and timothy and smooth brome on fine-textured soil—were especially important because of their dispersion and abundance, and persistence of litter production.

Key words: Soil stabilization, ground-cover plants, runoff, forest fire control

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by

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[1]Central headquarters maintained in cooperation with Colorado State University; research reported here was conducted in cooperation with South Dakota School of Mines and Technology at Rapid City.

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Introduction

Accelerated runoff and soil erosion are natural aftereffects of many intense forest burns. Nature alone will eventually restore a burned area to a condition of stability and equilibrium, but perhaps not for a long time. Consequently, artificial measures are planned to counteract natural destructive forces, and thus speed up the soil stabilization process.

Rehabilitation often consists of a combination of overlapping measures. With more complete understanding of basic runoff-erosion relationships and trends, treatment overlap and overall cost of rehabilitation may be reduced.

The 4,500-acre Deadwood fire of September 1959 provided an opportunity for study and evaluation of specific aspects of applied rehabilitation measures. Precipitation variables and ground-cover development were analyzed to determine their relationship to trends in surface runoff and erosion.

The Burn

Site Characteristics

The burn area (fig. 1) is in the highest precipitation zone of the Black Hills. Annual precipitation averages nearly 28 inches, and ranged from 18.0 to 48.4 inches over a 34-year period of record at Deadwood. Most abundant precipitation is produced by frontal-type storms during May and June. Convective thunderstorms and high-intensity rainfall are most common in July, and gradually diminish through August and September. Snowfall accounts for practically all precipitation from October through April. Heavy, wet spring snows are fairly common, and a number of rain-on-snow events have caused widespread flooding over the Black Hills area.

Both crystalline and sedimentary rock formations account for wide soil variations in the burn area.

Second-growth ponderosa pine[2] 80 to 90 years old dominated the area. Stands were typically dense post-pole size trees with small intermingled patches of sawtimber. Forest floor vegetation was sparse, a common condition in the typically dense second-growth pine stands of the Black Hills. Little other vegetation was present except for sparse grass cover and some common juniper on south slopes and along the crests of some rocky ridges, and scattered bearberry and creeping mahonia.

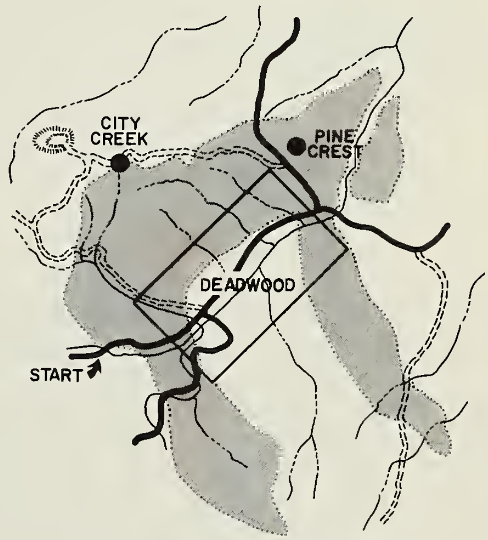

Figure 1.--Map of the September 1959 Deadwood Burn and surrounding area (Black Hills, South Dakota).

The Fire

The Deadwood Fire started on September 8, 1959, and within 24 hours burned over an area of about 4,500 acres. Fire danger was extreme throughout the period. Virtually all trees were killed and all forest floor organic matter was consumed over extensive areas. In early stages, when hottest, the fire moved across a series of steep side-by-side watersheds that drain almost directly south into the town of Deadwood (fig. 1), which itself was threatened by fire that burned into the outskirts.

[2] *Common and botanical names of plants mentioned are listed on page 12.*

Rehabilitation Measures

Extensive rehabilitation measures included artificial seeding of adaptable grasses and legumes on 4,011 acres. The entire treatment was designed to reduce by 68 percent the estimated potential flood damage from a 10-year-frequency storm in the first year after the fire.

Because of the threat of flooding during the normally heavy precipitation period of spring and early summer, primary treatment started while snow remained on the ground, and concluded with the April 4-8 helicopter seeding (on snow) of 11 pounds per acre of a grass-legume mixture:

Species	Pounds/acre
Timothy	3
Smooth brome	3
Kentucky bluegrass	2
Yellow sweetclover	2
Hairy vetch	1
Total	11

The Study Area

Two distinctly different areas were selected for detailed study. One was at the head of City Creek (fig. 1) on stony-loam soil developed from fine-grained Tertiary igneous intrusives or Precambrian quartz-mica or mica schists. Elevation was 5,400 feet (MSL). The other was at Pine Crest, several miles to the east, at elevation 4,900 feet in an area of finer textured loam to clay soil derived from massive light-colored Pahasapa limestone of Paleozoic origin.

At each site, eight 1-milacre runoff plots were installed in July and early August 1960; four on a south- to southwest-facing slope, and four on the north- to northeast-facing slope just over the adjacent ridge. By July some seeded species were becoming well established, and native cover was starting to reappear.

Two plots in each group of four were intentionally selected at sites on which total ground cover was relatively sparse, and two where cover was already relatively dense. Obvious atypical rock concentrations or other soil surface conditions were carefully avoided. Initial ground-cover densities (live vegetation plus litter) ranged from about 10 to 80 percent at City Creek and 10 to 33 percent at Pine Crest. Plots with the highest initial ground-cover densities generally had the highest percentages of seeded plant species.

The plots were 4 by 10.9 feet, with the long axis parallel to the slope (fig. 2). Sheet-metal frames were driven 3 to 4 inches into the soil. A collection trough along the lower boundary of each plot funneled runoff into a collection tank. Runoff plus sediment was measured by weighing. Sediment was then dried and weighed.

Figure 2.--Runoff plot installation. Plot frames were driven 3 to 4 inches into the ground in sections, then spliced together watertight.

Vegetation on all plots was surveyed and photographed during the period of maximum plant development in July or August each year of study. Six 1- by 2-foot subplots were examined on each 1-milacre runoff plot. During the same periods, surveys were also made on 2-square-foot plots at 50- to 100-foot intervals on two cross-country transects in the vicinity of each of the two major study sites. Number of plots per transect ranged from 10 to 30. Percentage live vegetation, litter, exposed rock, and bare soil on each runoff subplot and each transect plot were estimated visually. All identifiable plant species were listed. The three dominant species were then ranked 3, 2, or 1 in descending order of abundance and proportion of ground cover. The numerical ranking of the three most dominant species on each observation plot made it possible to define general ground-cover density and composition trends.

Primary climatic records were obtained with one centrally located standard precipitation gage and one recording gage at each of the two sites. Precipitation records were collected at monthly intervals during the winter months (October-March). All

plots were checked at the same time, and any snowmelt runoff was measured. More frequent observations were started prior to the general thaw, usually in March, and both precipitation and runoff observations were continued at 1-week intervals through September. More frequent measurements were taken in case of major storms. Plot runoff observations were started in August 1960 and continued through the growing season of 1963.

The first two postburn years were unusually dry, and the third and fourth years were unusually wet (table 1). Calendar year 1961 ranked lowest of 34 years of record at Deadwood. Precipitation then rose to far above average in 1962. Individual storms were larger and more intense than in the other years. In May alone 13.7 inches fell at City Creek and 11.6 inches at Pine Crest. The calendar year ranked fourth wettest of the 34 years of record. Calendar year 1963 continued above average, especially the winter months, and ranked fifth wettest of record.

Table 1.--Seasonal precipitation by water years at the two study sites

Water year	City Creek		Pine Crest	
	Oct.-Apr.	May-Sept.	Oct.-Apr.	May-Sept.
	- - - - - - Inches - - - - - -			
1960-61	8.48	9.64	([1])	8.16
1961-62	12.44	27.61	7.32	25.70
1962-63	19.10	14.62	12.28	13.06
1963-64	11.48	([2])	7.50	([2])

[1]Prior to installation of gages.
[2]Records discontinued.

Study Results

Ground-cover Density and Composition

Despite below-average precipitation through the winter and spring months (1959-60), some of the seeded species germinated and became established quickly, and some native species germinated or sprouted and started to regrow. Ground cover was already significant though highly variable when plots were installed in July and early August 1960. Precipitation had been just over 1 inch in May (less than 25 percent of average), about 3.75 inches in June (about 85 percent of average), and 1.6 inches (about 50 percent of average) in July.

"Patchiness" of ground cover when plots were selected and installed was striking; a broad range of immediate runoff and erosion potentials was evident at both sites (figs. 3, 4). The primary composition trends are illustrated in figure 5.

Highlights of ground-cover density and composition trends at City Creek during the 4 years of study were:

1. Quick establishment and persistent dominance of timothy.
2. Slowly increasing prominence of smooth brome (seeded), snowbrush ceanothus, and creeping mahonia (natives).
3. Sharp increase of Kentucky bluegrass in 1962 in apparent response to the far-above-average precipitation.
4. Initial prominence of American dragonhead, Carolina geranium (both native annuals), and yellow sweetclover (seeded biennial), and their almost complete disappearance by the second or third growing season.

Ground-cover density and composition characteristics and trends were somewhat different at Pine Crest. Main characteristics there were:

1. Initial prominence of seeded sweetclover and its apparent demise.
2. Codominance of seeded timothy.
3. The slow persistent increase and final prominence of smooth brome (seeded) and creeping mahonia (native).
4. Initial prominence of Carolina geranium (native annual) and its almost complete disappearance in the second growing season.

The major differences in cover density and composition between the two sites appear to have been due primarily to basic soil differences. Ground cover developed more quickly and to higher initial density on the coarse-textured soil at City Creek than on the finer textured, limestone-derived soil at Pine Crest. Pine Crest caught up quickly, however. By the end of the 1962 growing season, both sparse and dense plots at Pine Crest had more live cover than at City Creek. Some of the dense plots at City Creek appear to have reached their maximum production of live vegetation as early as 1960, and all plots by the end of the growing season in 1962. This contention is supported by the fact that there was an appreciable drop in amount of live cover on seven of eight plots at City Creek from 1962 to 1963, despite near- or slightly above-average precipitation, while live cover remained static or further increased at Pine Crest. Cover developed more rapidly at City Creek, but the Pine Crest site appeared to have the higher production potential.

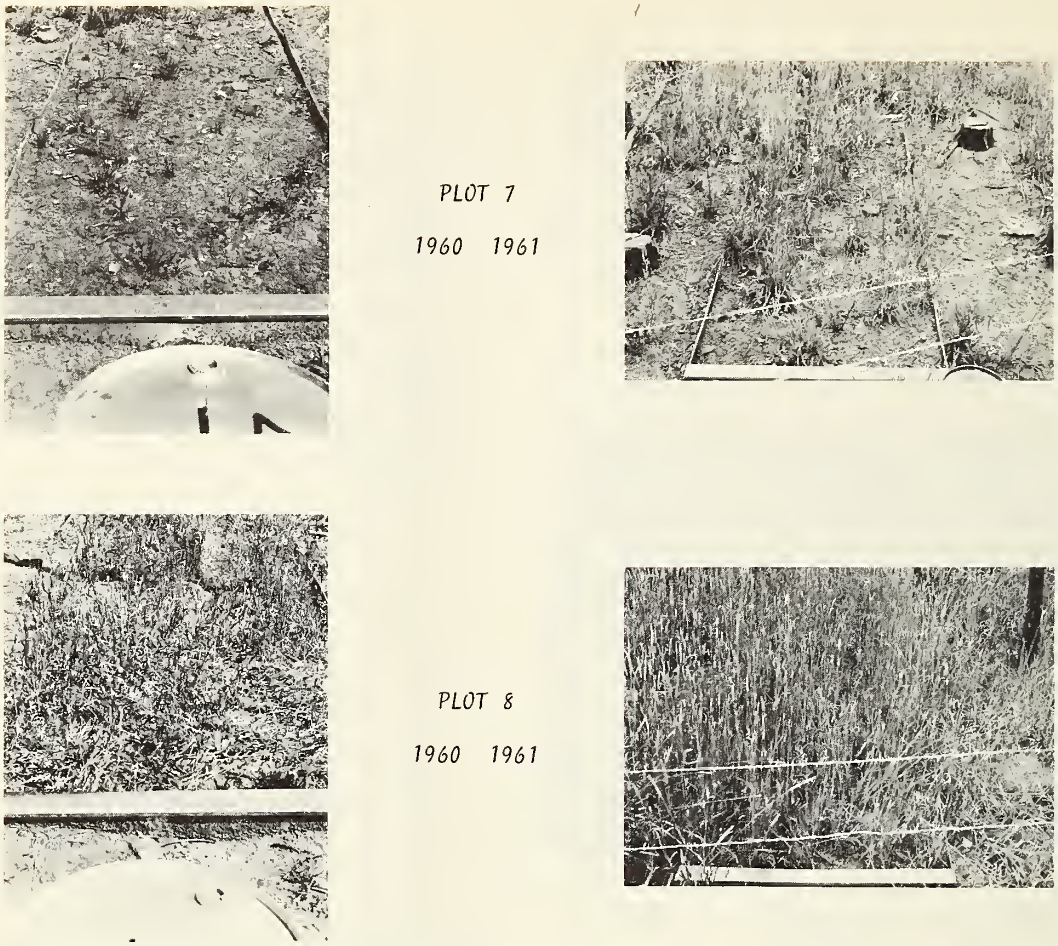

Figure 3.--Runoff plots 7 and 8 on a southwest-facing slope at City Creek in August 1960 and August 1961. A large difference in runoff and erosion potential between plots and between years is visible.

All of the seeded species except hairy vetch were important cover components at one or both of the sites at some time during the study period.

Timothy, which was important at both sites throughout the study, consistently maintained a higher degree of dominance at City Creek than at Pine Crest. Kentucky bluegrass became an important cover component at City Creek in 1962 but never was important at Pine Crest. Smooth brome increased slowly but surely and became an important species at both sites by the fourth growing season. Growth was generally more vigorous and of higher ranking at Pine Crest, however, where it was codominant with timothy and creeping mahonia in the general area at the end of the study.

Yellow sweetclover showed markedly different behavior at the two sites. New seedlings were abundant at both sites in 1960. At City Creek, most of the second-year growth was spindly and weak; at Pine Crest, it was tall and vigorous. The third season, practically none could be found at City Creek. First-year seedlings were abundant at Pine Crest in 1962 and again in 1963, but few developed into mature second-year plants.

From 15 to 20 more species were present each year at both sites than are shown in figure 5. Pine Crest generally had the greater variety of native species, and they made up a larger percentage of total cover than at City Creek. The more important of these easily observed but less frequently encountered species, mostly shrubs, were:

City Creek	Pine Crest
Spirea	Serviceberry
American red raspberry	Clematis
Spreading dogbane	Spreading dogbane
Common chokecherry	Common chokecherry
Rose species	Aster species

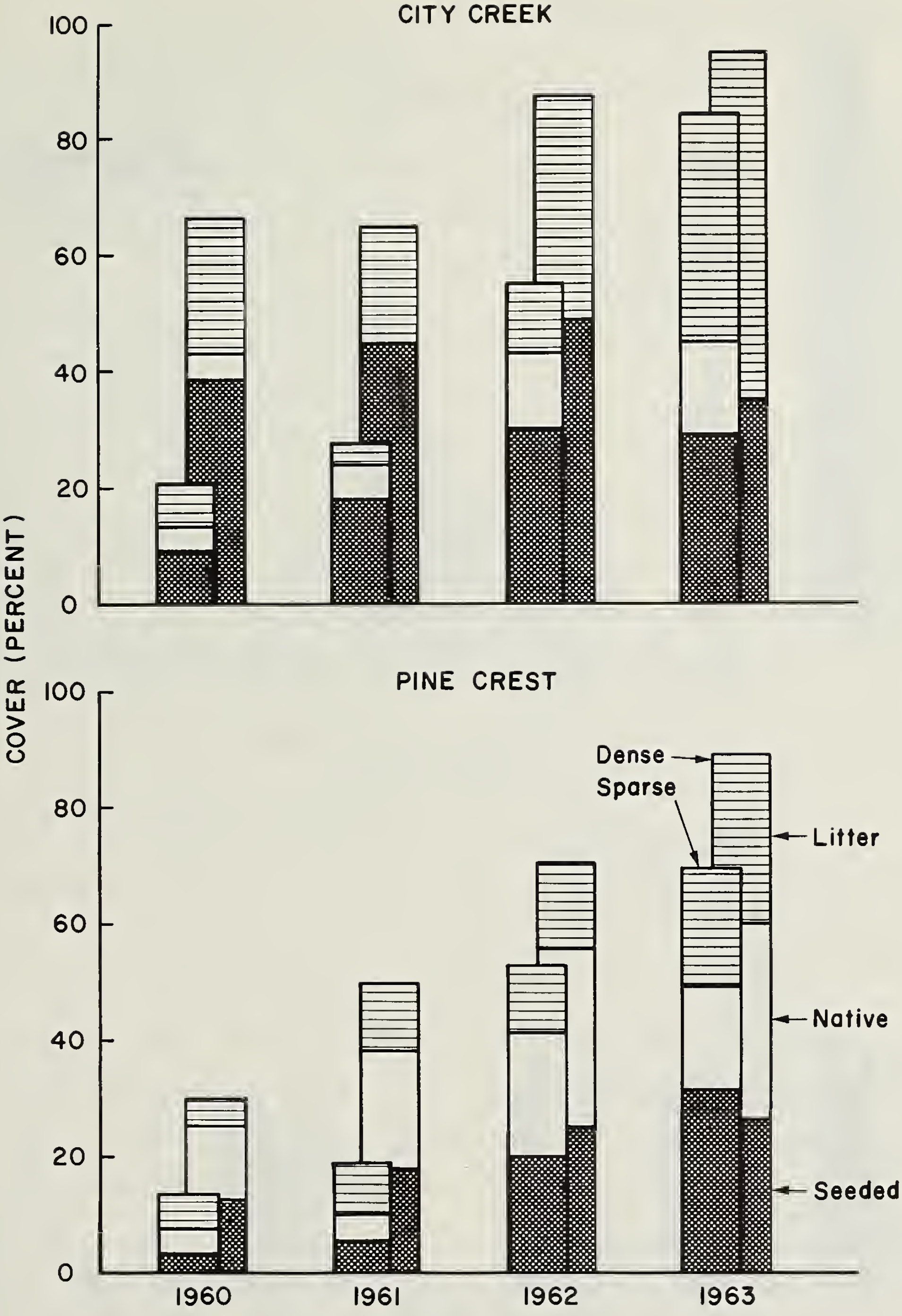

Figure 4.--Live vegetation (native and seeded) and litter-density trends on City Creek and Pine Crest runoff plots. Each bar represents the yearly average of four plots.

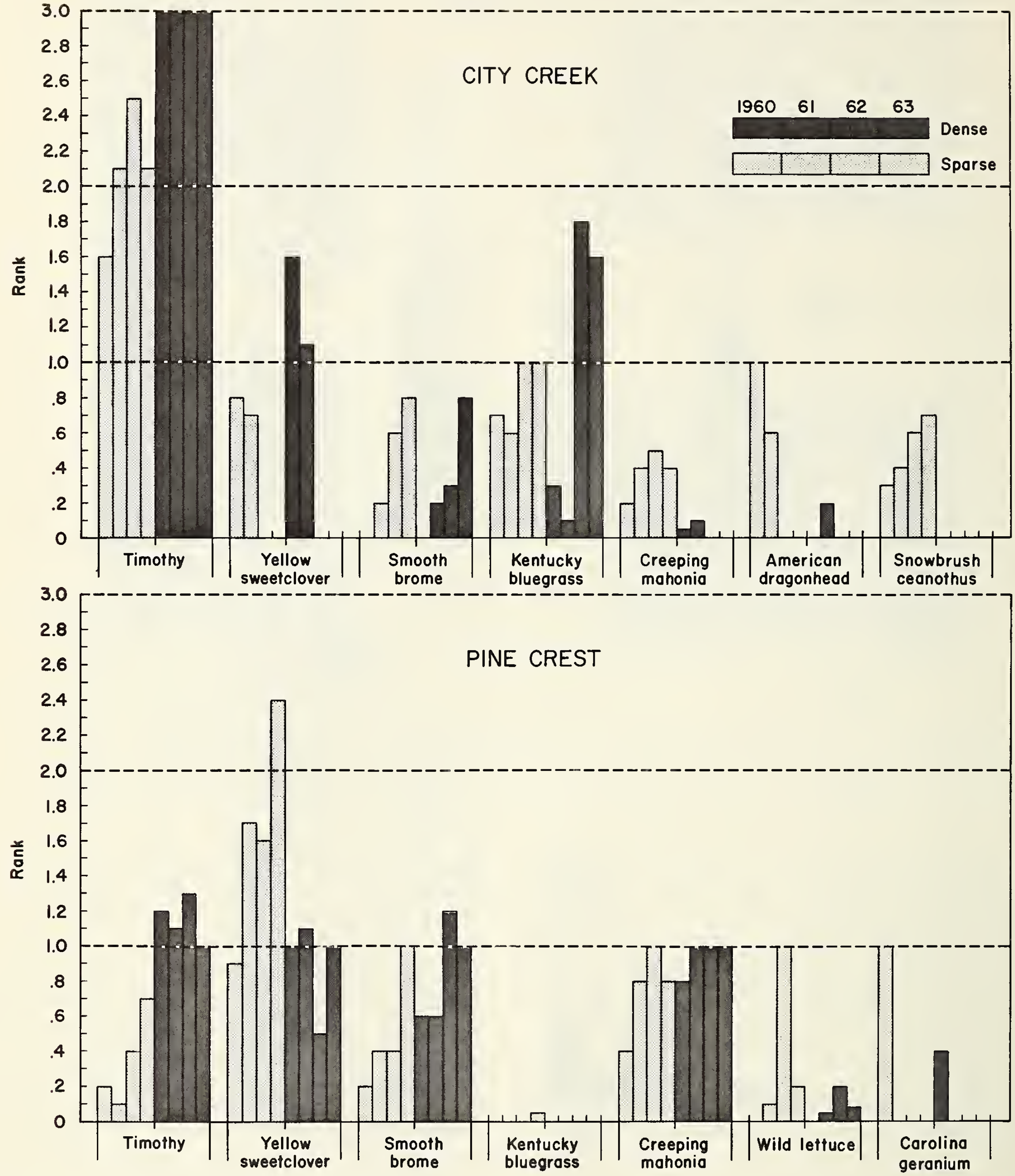

Figure 5.--Primary ground cover composition trends at City Creek and at Pine Crest in terms of cover rank, 1960-63.

Summer Runoff and Sediment

Between August 5 (date runoff-plot installations were completed) and September 30, 1960, a total of 3.91 inches of precipitation fell at City Creek and 3.93 inches at Pine Crest. Runoff was significant on only two occasions (table 2)—August 5-8 when 1.52 inches of precipitation fell at City Creek and 1.33 inches at Pine Crest, and August 19 when 1.15 inches was recorded at City Creek and 1.60 inches at Pine Crest. From limited records at City Creek, rainfall intensities apparently were no greater and probably were less than for comparable amounts of rainfall later in the study. More sediment came off all the plots in these two storm periods than in all of the three following summer seasons combined. Although some of this sediment may have resulted from installation disturbance, the inverse relationship of both runoff and sediment with ground cover is obvious.

Table 2.--Total summer storm runoff and sediment between August 5 and September 30, 1960

Site and plot cover class	Runoff[1]	Sediment[1]	Ground cover[2]
	Inches	Pounds/acre	Percent
CITY CREEK:			
Dense	0.50	757	67
Sparse	.89	4,472	20
PINE CREST:			
Dense	.70	2,883	30
Sparse	1.44	13,246	13

[1]Average of four plots.
[2]Live vegetation plus litter.

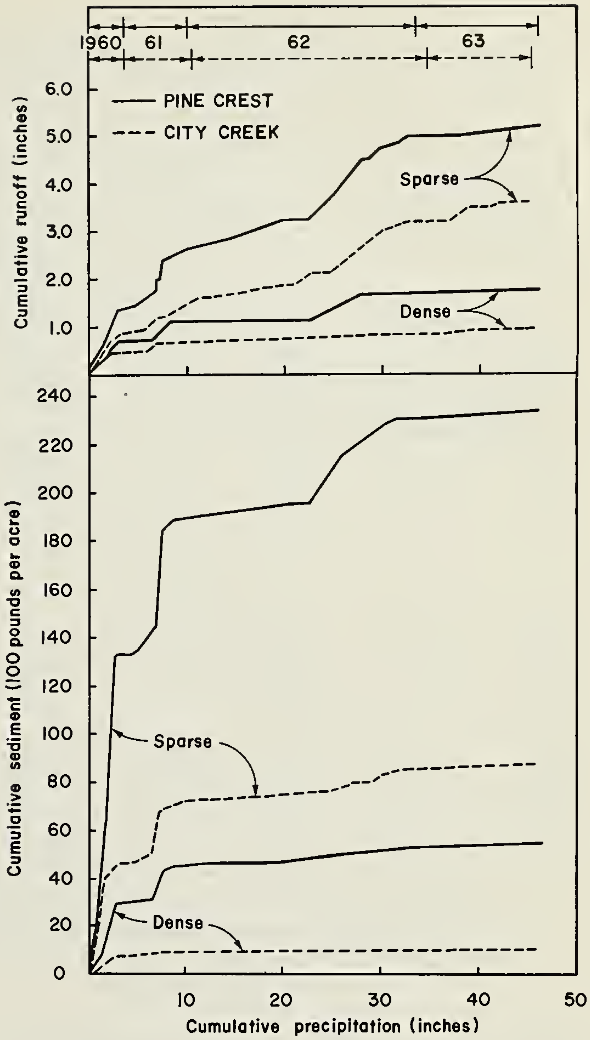

Figure 6.--Mass plot of summer storm runoff against precipitation and of sediment production in relation to gross precipitation, 1960-63 inclusive, at the two study sites.

Rates of runoff and sediment accumulation per unit of cumulative gross precipitation declined sharply in succeeding years (fig. 6). The apparent trends continued in the same order as initial 1960 differences in ground cover (live vegetation plus litter) between sparse- and dense-cover plots at the two sites and between sites. In these comparisons, north- and south-slope plots were combined since there were no clearly apparent or consistent effects of aspect, slope, or soil differences.

Several midseason accelerations of runoff and sediment accumulation cannot be attributed to decline in ground cover, since they occurred when vegetation was near its maximum seasonal development. They can more obviously be explained by seasonal variation in precipitation characteristics.

Regression techniques were used in attempting to account for these midseason anomalies and to quantitatively test the runoff and sediment production trends. Regressions of runoff and sediment production on gross precipitation were calculated for individual years. The rationale for computing direct regression of sediment on precipitation rather than on runoff is drawn from several well-known sources (Ellison 1945, Musgrave 1947, USDA 1961), who define soil detachment and sheet erosion in terms of the kinetic energy of rainfall and site characteristics, including soil erodibility and ground

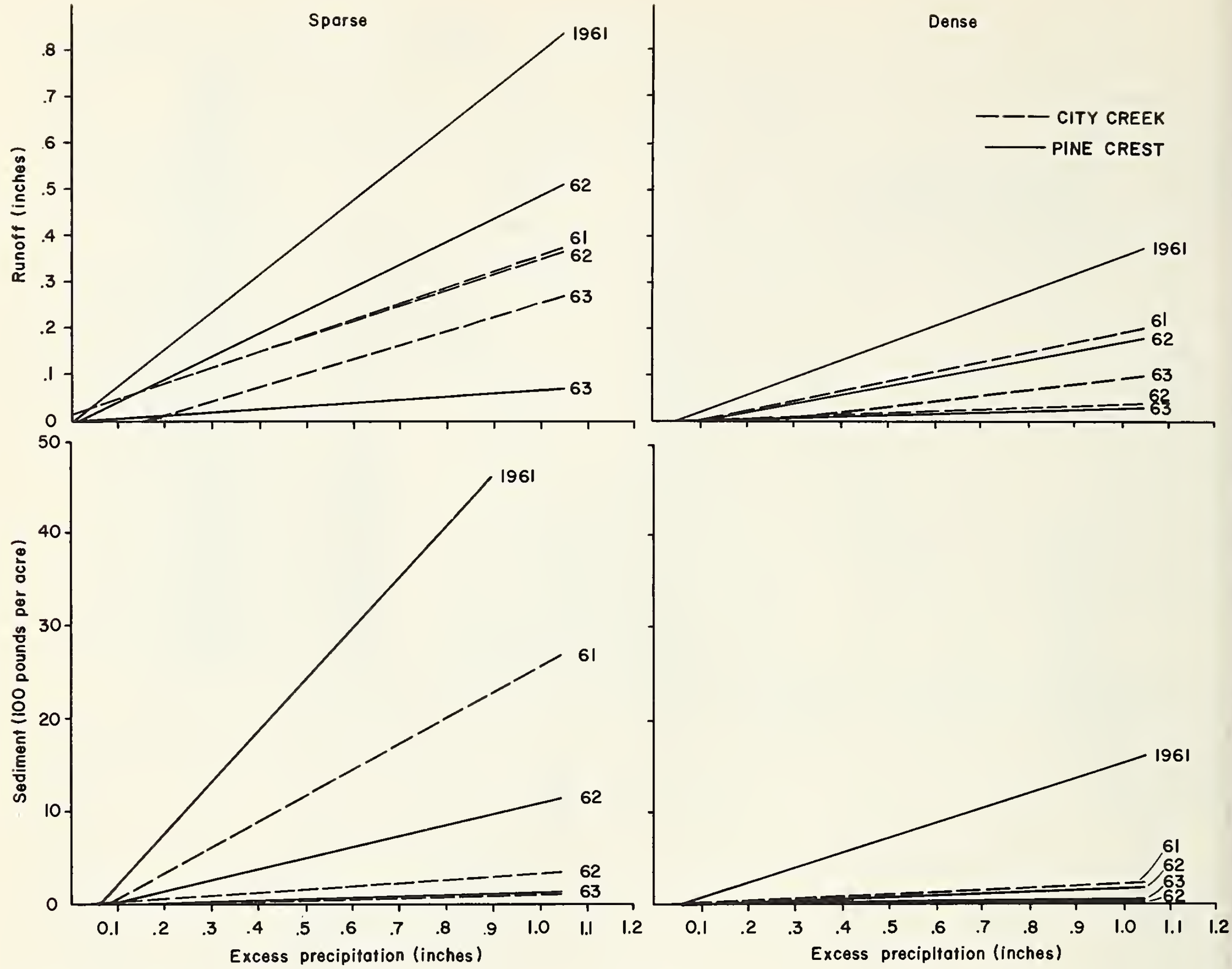

Figure 7.--Regression of summer storm runoff and sediment production on 0.03-inch-per-minute precipitation excess for 1961, 1962, and 1963.

cover. Unfortunately, the year 1960 could not be included in these analyses because of incomplete precipitation records. Of the remaining 3 years, gross precipitation alone accounted for a significant portion of runoff and sediment variance only in the exceptionally wet year 1962 ($P. \leq 0.05$). Thus, gross precipitation was a relatively poor indicator of runoff and sediment production.

Precipitation intensity was then introduced into the analysis in the form of an excess rainfall factor, which in effect was an indirect expression of infiltration rates. The factor was computed as total rainfall during a measurement interval that fell at a rate in excess of 0.03 inch per 5 minutes (0.36 inch per hour). Both higher and lower base rates were tested, but the 0.03-inch factor accounted for the most consistent proportion of runoff and sediment variance throughout the period of record.

The excess rainfall-runoff relationships (fig. 7, table 3) were all significant to highly significant ($P \leq 0.05$) in all 3 years on both classes of plots at both sites. The excess rainfall-sediment production relationships (fig. 7, table 3) were also all significant to highly significant except for City Creek dense-cover plots in 1963, when sediment production was too low to define a statistically significant trend. Cumulative plottings of runoff and sediment against excess precipitation were obviously less erratic than the plots against gross precipitation (fig. 6).

The year-to-year trends were tested by comparing regressions of runoff and sediment production on the excess rainfall factor by individual years. This is a more exact method than use of covariance to test significance of changes in slope of the overall run-

Table 3.--Regression of summer storm runoff (Y = inches) and sediment production (Y = pounds per acre) on 0.03 inch per 5 minutes excess rainfall (X), and estimates for the overall average 0.24 inch of excess rainfall per observation interval

Site and Year	Coefficient of determination: Dense	Coefficient of determination: Sparse	Regression equation constants for Y = a + bX: Dense (a)	Dense (b)	Sparse (a)	Sparse (b)	Estimates[1]: Dense	Estimates[1]: Sparse
			RUNOFF (Inches)					
CITY CREEK:								
1961	0.647**	0.425*	-0.015	0.2054	0.011	0.3419	0.034	0.093
1962	.546**	.703**	- .001	.0363	.013	.3367	.008	.094
1963	.956**	.965**	- .028	.1204	- .050	.3070	.001	.024
PINE CREST:								
1961	.791**	.898**	- .016	.3722	- .006	.8017	.073	.186
1962	.819**	.892**	- .020	.1901	- .011	.4934	.026	.108
1963	.858**	.821**	- .002	.0308	- .000	.0675	.005	.015
			SEDIMENT PRODUCTION (Pounds/acre)					
CITY CREEK:								
1961	.649**	.749**	- 15.8	235.9	-221.9	2770.4	41.0	443
1962	.704**	.866**	- 0.4	8.1	- 2.3	327.1	1.5	76
1963	.438NS	.536*	- 2.2	17.4	4.6	84.1	2.0	25
PINE CREST:								
1961	.832**	.872**	- 92.0	1615.9	-291.6	5465.8	296.0	1020
1962	.843**	.935**	- 8.9	169.1	-103.3	1205.2	32.0	186
1963	.790**	.788**	.2	47.5	- 1.5	115.1	12.0	21

[1] Separation lines indicate approximate points in time after which it is postulated that runoff and sediment production rates were within tolerable limits.
* Significant at .05 level.
** Significant at .01 level.
NS Not significant at .05 level.

off and sediment accumulation curves (Dawdy and Matalas 1964, p.8-76). All comparisons were based on assumption of linear relationships, since tests of several of the more questionable cases did not clearly indicate curvilinearity. Where variances were significantly different, approximate tests were made with adjusted degrees of freedom.

Three broad generalizations are at first apparent in figure 7 and in table 3:

1. There was a significant drop in runoff and sediment production per unit of excess rainfall from one year to the next on both sparse- and dense-cover plots at both sites.
2. There was significantly less runoff and sediment production per unit of excess rainfall from dense- than sparse-cover plots at both sites in all 3 years.
3. There was significantly less runoff and sediment production from City Creek sparse- and dense-cover plots than from Pine Crest sparse- and dense-cover plots in all 3 years.

These generalizations indicate decreasing runoff and sediment production as ground-cover density increased with time. However, there are several noteworthy exceptions to these general interpretations.

The City Creek sparse-cover plots did not show significant change in the excess-rainfall/runoff-production relationship from 1961 to 1962 despite a sharp increase in average ground-cover density. The regression lines in figure 7 coincide almost perfectly, and the regression equations in table 3 are almost identical. There also was no significant change in runoff production per increment of excess rainfall from 1962 to 1963. The slope of the regression remained almost the same. However, a significantly greater amount of excess rainfall was necessary to start runoff production in 1963 than in 1961 or 1962. Hence, a given amount of excess rainfall would have been expected to produce significantly less runoff in 1963 than in 1961 or 1962.

The 1961 and 1962 regressions for City Creek sparse-cover plots indicate slight amounts of runoff when there was no rainfall excess. Although no overall slope effects were readily apparent, slope steepness may have been a factor in this rather atypical runoff behavior. Average slope gradient was 8 percent greater than City Creek dense-cover plots and 12 percent greater than the Pine Crest sparse-cover plots.

A second exception involves runoff production rates on City Creek dense-cover plots. They show a significant decline from 1961 to 1962 as average total ground cover increased from about 65 to 87 percent, but the trend reversed in 1963. Runoff increased slightly despite a further increase in total ground cover. The only apparent explanation is the substantial drop in live cover from 1962 to 1963; the increase in total cover was due primarily to litter carryover from grass production in 1962.

A third exception involves comparison of runoff production rates at the two sites. City Creek dense- and sparse-cover plots had more total ground cover and produced less runoff per increment of excess precipitation than Pine Crest dense- and sparse-cover plots in both 1961 and 1962. In 1963 the situation reversed. Pine Crest plots yielded significantly less runoff per increment of excess precipitation than City Creek. Total ground cover continued slightly greater at City Creek than at Pine Crest, but for the first time Pine Crest had more live cover than City Creek.

The initial generalizations are more consistent for sediment comparisons than for runoff. There are no noteworthy exceptions, which in itself is significant. For example, runoff relationships were almost identical on City Creek sparse-cover plots in 1961 and 1962, yet there was a significant drop in sediment production per increment of excess precipitation. Hence, there was a significant drop in sediment production per unit of runoff. In fact, the decline in sediment production rates was of greater relative magnitude than for runoff throughout the study period, which indicates a steady reduction of sediment yield per unit of runoff.

Winter Runoff

The test plots also yielded significant winter runoff, with pronounced differences between the two sites. The City Creek plots consistently yielded from two to six times more snowmelt runoff than rainfall runoff. Pine Crest plots, on the other hand, produced only from about one-fourth as much to about the same amount of snowmelt runoff as rainfall runoff, and only about one-third to one-eighth as much as City Creek. Snowmelt runoff did not produce significant amounts of sediment.

The difference in snowmelt runoff between the two sites was primarily due to differences in amount and distribution of snow, and in the nature of soil freezing. The City Creek site characteristically received 1.5 to 1.7 times more winter precipitation than Pine Crest. At City Creek snow accumulated and remained on the ground all winter. Little snow accumulated at the more exposed and windswept Pine Crest site, and what did accumulate usually melted between storms.

Concrete frost characteristically formed at City Creek and made the soil practically impervious to water. On a number of occasions, sometimes in midwinter, a 1- to 2-inch-thick semifluid layer of free water and soil was noted on top of still solidly frozen soil. No such condition was ever noted at Pine Crest; frost crystals could be easily seen in the top 3 to 4 inches of soil, but the soil could still be turned easily with a shovel.

Winter runoff may occur in any of the winter months in the Black Hills. South and southwest slopes yield runoff more evenly distributed through the winter months than do the north-facing slopes. The general thaw, which usually occurs in late March or early April, produces the bulk of snowmelt runoff from north slopes.

At no time during the study was there consistent evidence of a relationship between snowmelt runoff and ground cover. The amount and time distribution of snowmelt runoff was controlled primarily by amount and aerial distribution of snow and by aspect.

Discussion

Summer storm runoff was under control and the soil had been stabilized by the end of the 4 years of study—considerably sooner on some sites.

From a strictly statistical standpoint, the plots in general yielded significant though declining amounts of runoff and sediment per increment of excess precipitation to the end of the study. Consider, however, the production of runoff and sediment in relation to ground-cover development trends.

Estimated runoff and sediment for the 0.24-inch mean of excess rainfall per observation interval for 3 summers of record at both sites are shown in

table 3. A plot of these values against average total ground cover showed a progressive deceleration of runoff production as total ground cover increased to about 60 percent. With further increase in ground cover, runoff declined at a slow, steady rate of only about 0.01 inch per 10 percent increase in ground cover. Sediment production showed an even sharper deceleration with increasing ground-cover density, and it too leveled out to a low, constant rate at about 60 percent total ground cover.

In a 1951 study of watershed protection requirements, Packer (1951) showed a similar type of relationship, with runoff and sediment production leveling off to insignificant rates at about 70 percent total ground cover. His study involved infiltrometer tests on wheatgrass and cheatgrass range on coarse-textured granitic soils in south-central Idaho. A similar infiltrometer study on finer textured soils in a subalpine range in central Utah[3] showed continuing deceleration of runoff all the way to 100 percent ground cover, but a deceleration of sediment production to a slow, constant rate at about 65 percent total ground cover. In both these studies, the approximate ground-cover densities at which sedimentation rates became constant were considered the safe minimum for site stability. If the same criteria are applied to the present study, the City Creek dense-cover plots reached a point of minimum stability by the end of the first year after the burn, the Pine Crest dense plots by the end of the summer in 1962, and the sparse-cover plots at both sites by the end of the summer in 1963 —all within 3 to 4 years after the fire.

If the transects are considered more representative of the entire burn, the 60 percent ground cover criteria indicates that generally east-facing slopes in the City Creek area were stabilized by the end of 1961, generally west-facing slopes not until about midseason 1963, and the general Pine Crest area by midsummer 1962.

Seeded species dominated the cover at both sites throughout the study (fig. 5). Seeded species approached or exceeded 50 percent of live cover and reached nearly 100 percent. Actual cover provided by seeded species also increased steadily except for dense-cover plots in 1963. These plots had apparently already reached their herbaceous production potential, and live cover declined in apparent response to a drop in rainfall from the unusually wet year 1962.

Sweetclover was a relatively important cover component at both sites at the start, but quickly gave way to the grasses—timothy and Kentucky bluegrass at City Creek, and timothy and smooth brome at Pine Crest. These seeded grasses played key roles in the stabilization process in two special respects. In growth characteristics they provided a more evenly dispersed cover than native species—an important requirement in site stability[3] (Packer 1951)— and they supplied the bulk of the steady accumulation of litter cover.

In the early stages of vegetation development, when density was low, the cover provided by seeded species must have supplemented cover provided by native species, since total cover was generally so sparse as to rule out the likelihood of serious competition. Even with liberal allowance for increasing competition as cover developed, it is reasonable to postulate that neither site would have reached a 60 percent ground-cover requirement for minimum soil stability within 4 years without the seeding.

Summary and Conclusions

A September 1959 fire destroyed virtually all of the dominant ponderosa pine forest and understory vegetation on 4,500 acres of sloping watershed land adjacent to the town of Deadwood, South Dakota. Over extensive areas, humus was consumed down to mineral soil.

Emergency rehabilitation measures applied the following spring included aerial application of 11 pounds per acre of a grass-legume seed mixture.

Small plots were installed during the summer of 1960 to study surface runoff and soil erosion trends in relation to establishment of seeded and native vegetation.

Summer storm runoff and sediment production were closely related to a 0.36-inch-per-hour excess rainfall factor. Rates of production per unit of excess rainfall declined significantly each successive year as ground cover developed. Gross rainfall was a poor indicator of both runoff and soil erosion. Snowmelt on frozen ground produced substantial winter runoff at one site, but amounts of sediment were insignificant.

[3] Orr, Howard K. Runoff and erosion trends on two subalpine watersheds in central Utah. 1956. (Unpublished report on file at Intermountain Forest and Range Exp. Sta., U.S. Dep. Agr., Forest Serv., Ogden, Utah.)

As ground cover developed, summer runoff and erosion rates decelerated until cover density reached about 60 percent (live vegetation plus litter). As ground-cover density increased beyond 60 percent, the rates of surface runoff and sediment production decreased slowly and steadily. It is postulated that total ground cover must equal or exceed about 60 percent density for minimum tolerable runoff control and soil stability. With this criteria as a basis, portions of the burned area were stabilized by developing vegetation within the first growing season, and all of the sampled area was stabilized by the end of the fourth growing season.

Minimum soil stability probably would not have been achieved in four growing seasons on any of the sampled sites without artificial seeding. Seeded timothy dominated the ground cover on stony loam soils throughout the period of study, and seeded Kentucky bluegrass increased to second-place rating. On finer textured soil derived from limestone, smooth brome grass developed more slowly but was codominant with timothy by the end of the fourth growing season. Yellow sweetclover provided significant cover during the first two growing seasons, especially on the finer textured soil, then declined rapidly.

Literature Cited

Dawdy, D. R., and Matalas, N. C.
1964. Statistical and probability analysis of hydrologic data. III. Analysis of variance, covariance, and time series. Sec. 8-III, 68-90, illus. In Handbook of applied hydrology, edited by Ven Te Chow. New York: McGraw-Hill Book Co.

Ellison, W. D.
1945. Some effects of raindrops and surface-flow on soil erosion and infiltration. Amer. Geophys. Union, Trans. 26: 415-429, illus.

Musgrave, G. W.
1947. The quantitative evaluation of factors in water erosion—A first approximation. J. Soil and Water Conserv. 2: 133-138.

Packer, Paul E.
1951. An approach to watershed protection criteria. J. Forest. 49: 639-644, illus.

U. S. Department of Agriculture.
1961. A universal equation for predicting rainfall-erosion losses—An aid to conservation farming in humid regions. U. S. Dep. Agr., Agr. Res. Serv. Spec. Rep. 22-26, 11 p., illus.

COMMON AND BOTANICAL NAMES OF PLANTS MENTIONED

COMMON NAME	BOTANICAL NAME AND AUTHOR
SHRUBS	
American red raspberry	*Rubus strigosus* Michx.
Bearberry	*Arctostaphylos uva-ursi* (L.) Spreng.
Common chokecherry	*Prunus virginiana* L.
Common juniper	*Juniperus communis* L.
Creeping mahonia	*Mahonia repens* (Lindl.) G. Don
Rose	*Rosa* sp.
Serviceberry	*Amelanchier* sp.
Snowbrush ceanothus	*Ceanothus velutinus* Dougl.
Spirea	*Spiraea* sp.
TREES	
Ponderosa pine	*Pinus ponderosa* Laws.
LEGUMES	
Hairy vetch	*Vicia villosa* Roth
Yellow sweetclover	*Melilotus officinalis* (L.) Lam.
GRASSES	
Cheatgrass	*Bromus tectorum* L.
Kentucky bluegrass	*Poa pratensis* L.
Smooth brome	*Bromus inermis* Leyss.
Timothy	*Phleum pratense* L.
Wheatgrass	*Agropyron inerme* (Scribn. & Sm.) Rydb.
FORBS	
American dragonhead	*Dracocephalum parviflorum* Nutt.
Aster	*Aster* sp.
Carolina geranium	*Geranium carolinianum* L.
Clematis	*Clematis* sp.
Spreading dogbane	*Apocynum androsaemifolium* L.
Wild lettuce	*Lactuca* sp.

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Orr, Howard K.
1970. Runoff and erosion control by seeded and native vegetation on a forest burn: Black Hills, South Dakota. USDA Forest Serv. Res. Pap. RM-60, 12 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Growth of seeded species in combination with reestablishment of native vegetation reduced overland runoff and soil erosion to tolerable levels within one to four growing seasons. Gross rainfall was a poor indicator of runoff and soil erosion from small plots. Trends were best defined by declining rates of runoff and sediment production per unit of excess rainfall. Sixty percent ground-cover density (live vegetation plus litter) is postulated as the minimum necessary for soil stabilization. This cover density almost certainly could not have been reached within the 4-year study period without seeding. Seeded grasses—timothy and Kentucky bluegrass on coarse-textured soil and timothy and smooth brome on fine-textured soil—were especially important because of their dispersion and abundance, and persistence of litter production.

Key words: Soil stabilization, ground-cover plants, runoff, forest fire control

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About The Forest Service. . . .

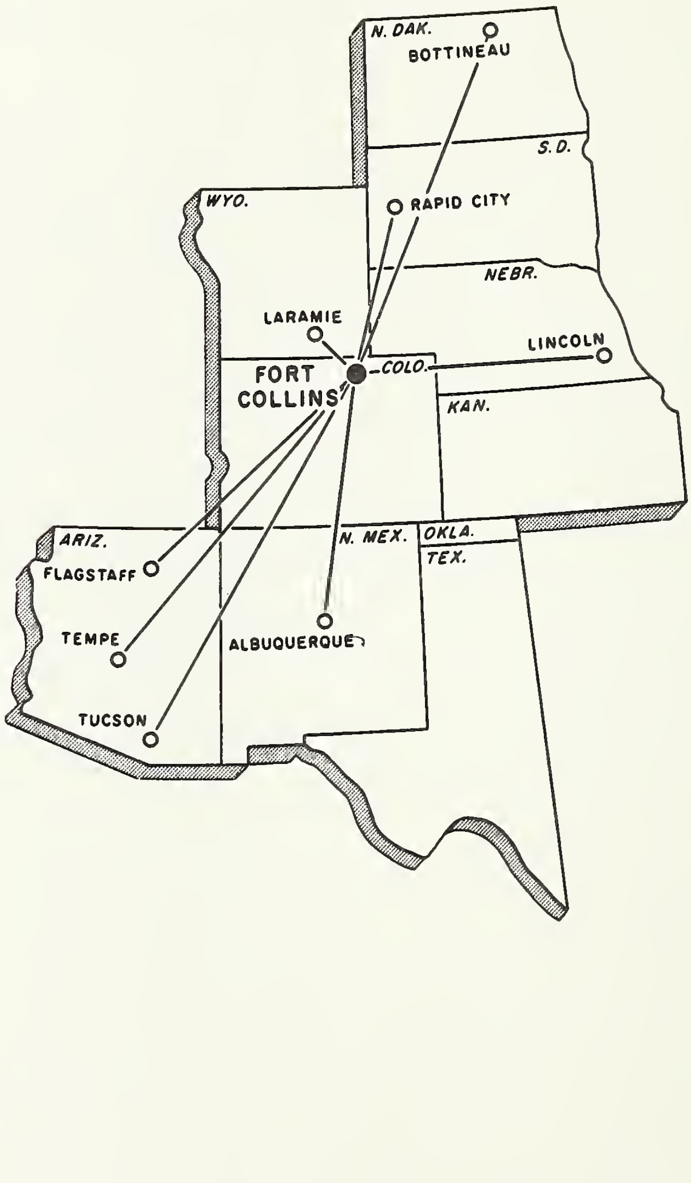
As our Nation grows, people expect and need more from their forests—more wood; more water, fish and wildlife; more recreation and natural beauty; more special forest products and forage. The Forest Service of the U. S. Department of Agriculture helps to fulfill these expectations and needs through three major activities:

- *Conducting forest and range research at over 75 locations ranging from Puerto Rico to Alaska to Hawaii.*
- *Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.*
- *Managing and protecting the 187-million acre National Forest System.*

The Forest Service does this by encouraging use of the new knowledge that research scientists develop; by setting an example in managing, under sustained yield, the National Forests and Grasslands for multiple use purposes; and by cooperating with all States and with private citizens in their efforts to achieve better management, protection, and use of forest resources.

Traditionally, Forest Service people have been active members of the communities and towns in which they live and work. They strive to secure for all, continuous benefits from the Country's forest resources.

For more than 60 years, the Forest Service has been serving the Nation as a leading natural resource conservation agency.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